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JPL

NASA SPACECRAFT TRANSPONDING MODEM

JEFF B. BERNER

SELAHATTIN KAYALAR

JONATHAN D. PERRET

TRANSPONDER FUNCTIONS
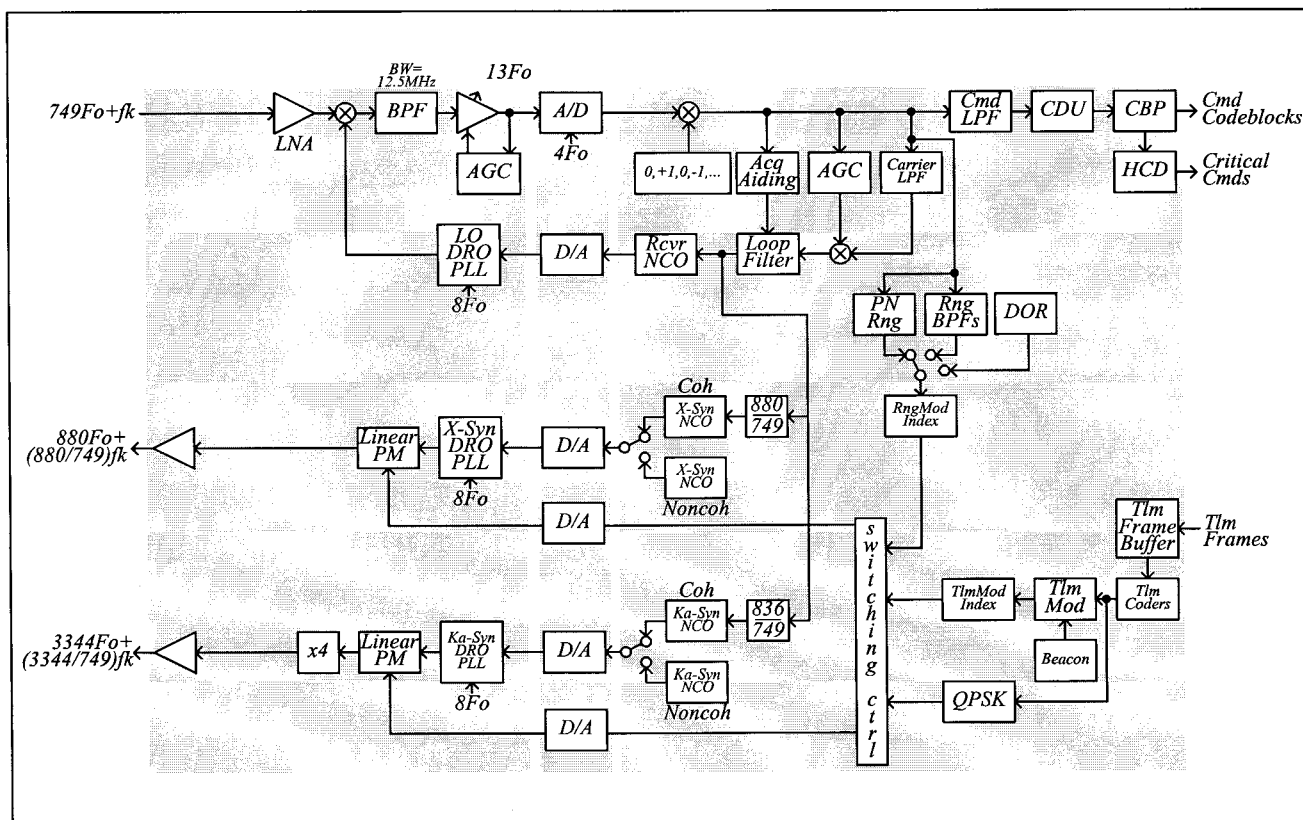
- TRACK X-BAND UPLINK CARRIER
- GENERATE X-BAND AND Ka-BAND DOWNLINK CARRIERS
- DEMODULATE AND DECODE UPLINKED COMMAND CODEBLOCKS
- PROVIDE THE FOLLOWING TELEMETRY FUNCTIONS:
  - CONVOLUTIONAL ENCODING (7, 1/2 AND 15, 1/6)
  - REED-SOLOMON ENCODING (INTERLEAVE DEPTH 1 AND 5)
  - TURBO ENCODING (RATE 1/3 AND 1/6)
  - FRAME-LEVEL INTERFACE TO SPACECRAFT DATA SUBSYSTEM
  - FRAME TIME-TAGGING
- PROVIDE THE FOLLOWING RANGING FUNCTIONS:
  - TURN AROUND RANGING
  - REGENERATIVE PN RANGING
  - DIFFERENTIAL ONE-WAY RANGING

SPACECRAFT TRANSPONDING MODEM

STM BLOCK DIAGRAM

UPLINK CARRIER PROCESSING

- SIGNAL LEVEL RANGE -158 TO -70 dBm
  - NOISE FIGURE OF 2.4 dB
- SINGLE STAGE DOWNCONVERSION
  - TRACKING LOOP CLOSED AT DOWNCONVERSION
- CONVERSION TO DIGITAL AT RATE 4F0 (F0 = ~9.565 MHz)
  - 8-BIT CONVERSION
  - FREQUENCY INTO ADC IS 13F0 (~124 MHz)
  - UNDERSAMPLING OUTPUTS CARRIER AT F0
- ADC OUTPUT MULTIPLIED BY (+1, 0, -1, 0, ...) AND DOWNSAMPLED TO 2F0, GENERATING I AND Q SAMPLE STREAMS
- I AND Q FILTERED TO 4.7 kHz AND USED IN TRACKING LOOP TOTAL POWER AGC
  - PROVIDES BANDWIDTH EXPANSION (FACTOR OF ~10)
- 40-BIT NCO USES AMPLITUDE AND PHASE DITHERING FOR SPUR REDUCTION (LESS THAN 80 dBc)
  - 6-BIT OUTPUT CONVERTED BACK TO ANALOG FOR PHASE LOCK LOOP CLOSURE

UPLINK CARRIER PROCESSING (CONT.)

- LOOP COEFFICIENTS STORED IN ROM
  - ALLOWS CUSTOMIZATION FOR INDIVIDUAL MISSIONS
- SWEPT CARRIER ACQUISITION
  - SIMULATES GROUND ACQUISITION SWEEP
- BOTH PERFECT AND IMPERFECT LOOPS PROVIDED
  - PERFECT LOOPS TRACK DOPPLER BETTER, BUT HAVE HIGHER DRIFT IN NOISE ONLY SITUATIONS
  - IMPERFECT LOOPS HAVE MUCH LESS DRIFT IN NOISE ONLY SITUATIONS, BUT HAVE POORER DOPPLER TRACKING PERFORMANCE
  - CAN BE IMPERFECT WHEN OUT-OF-LOCK AND PERFECT WHEN LOCKED
- NASA STANDARD COMMAND DETECTOR UNIT (CDU) IMPLEMENTED
  - SUBCARRIER TRACKING
  - BIT SYNCHRONIZATION
- COMMAND FRAME SYNCHRONIZATION AND BCH DECODING PROVIDED
  - INTERFACE TO SPACECRAFT COMMAND/DATA SUBSYSTEM (CDS) AT CODEBLOCK LEVEL

DOWNLINK CARRIER PROCESSING

- TWO NCOs PER BAND PROVIDED
  - ONE COHERENT WITH UPLINK CARRIER NCO
    - X-BAND SCALING 880/749
    - Ka-BAND SCALING 836/746
      - TIMES 4 IN ANALOG DOMAIN GIVES 3344/749 SCALING
  - ONE AT FIXED FREQUENCY (NON-COHERENT)
    - FREQUENCY VALUE SET IN CONFIGURATION ROM
- SAME NCO STRUCTURE AS UPLINK NCO
  - SPURS LESS THAN 80 dBc
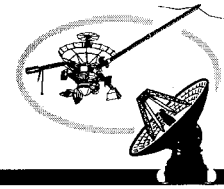
TELEMETRY PROCESSING

- DATA ENCODING
  - CONVOLUTIONAL
    - BOTH 7, 1/2 AND 15, 1/6
  - REED SOLOMON
    - INTERLEAVE 1, FRAME SIZE 1784
    - INTERLEAVE 5, FRAME SIZE 8920
  - CONCATENATED CONVOLUTIONAL/REED SOLOMON
  - TURBO
    - RATES 1/3 AND 1/6, FRAME SIZES 1784 AND 8920
- THREE SQUAREWAVE SUBCARRIERS (22.5 kHz, 360 kHz, AND 2.88 MHz)
  - SYMBOLS COHERENT WITH SUBCARRIER (NRZ-L FORMAT)
  - DATA RANGE 5 bps TO 320 kbps
- BIPHASE-L DIRECT MODULATION
  - UP TO 12 Msps
- MODULATION INDEX UP TO 90 DEGREES
- SYMBOL RATE CAN BE LINEARLY RAMPED, TO MATCH GROUND G/T PROFILE
  - 1.5 dB (X-BAND) AND 1.9 dB (Ka-BAND) GAIN IN DATA RETURN
- 4-TONE BEACON MODE SUPPORTED

RANGING PROCESSING

- TURN AROUND
  - DEMODULATE RANGING SIGNAL FROM UPLINK, FILTER AND MODULATE ONTO THE DOWNLINK CARRIER
  - TWO BANDWIDTHS PROVIDED (1.8 AND 6.1 MHz)
    - 6.1 MHz FOR TIMES WHEN RANGING POWER DOMINATES THE NOISE AND THE FILTERING OF HIGHER HARMONICS AFFECT THE DOWNLINK MODULATION
- REGENERATIVE
  - USES PN RANGING SIGNAL
  - TRACKS SIGNAL, REDUCING REMODULATED NOISE FROM 1.8 MHz TO LOOP BANDWIDTH
  - USES RANGING SIGNAL COHERENCY WITH UPLINK CARRIER TO SIMPLIFY IMPLEMENTATION
    - ONLY NEEDS FIRST ORDER LOOP TO TRACK SIGNAL
- DIFFERENTIAL ONE-WAY RANGING (DOR)
  - 2F0 (~19 MHz) TONE MODULATED ONTO DOWNLINK

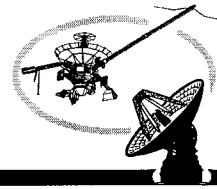# SPACECRAFT TRANSPONDING MODEM

CUSTOM ASICs

- TWO CUSTOM ASICs
  - MIXED SIGNAL (DESIGNED BY BOEING), USING NATIONAL 0.35 μm PROCESS
    - 1 8-BIT ADC AT 4F0
    - 5 6-BIT DAC AT 8F0
    - 1 8-BIT ADC AT LOW RATE FOR HOUSEKEEPING
    - 43,000 TRANSISTORS
    - 10.1 μm X 10.1 μm DIE SIZE
  - DIGITAL (DESIGNED BY JPL), USING NATIONAL 0.35 μm PROCESS
    - DOES ALL DIGITAL PROCESSING (CARRIER TRACKING, COMMAND PROCESSING, TELEMETRY, RANGING, DATA BUS INTERCOMMUNICATION)
    - OPERATES AT 8F0
    - 1.9M TRANSISTORS
    - 13.6 k X 13.9 k μm DIE SIZE

CONSTRUCTION
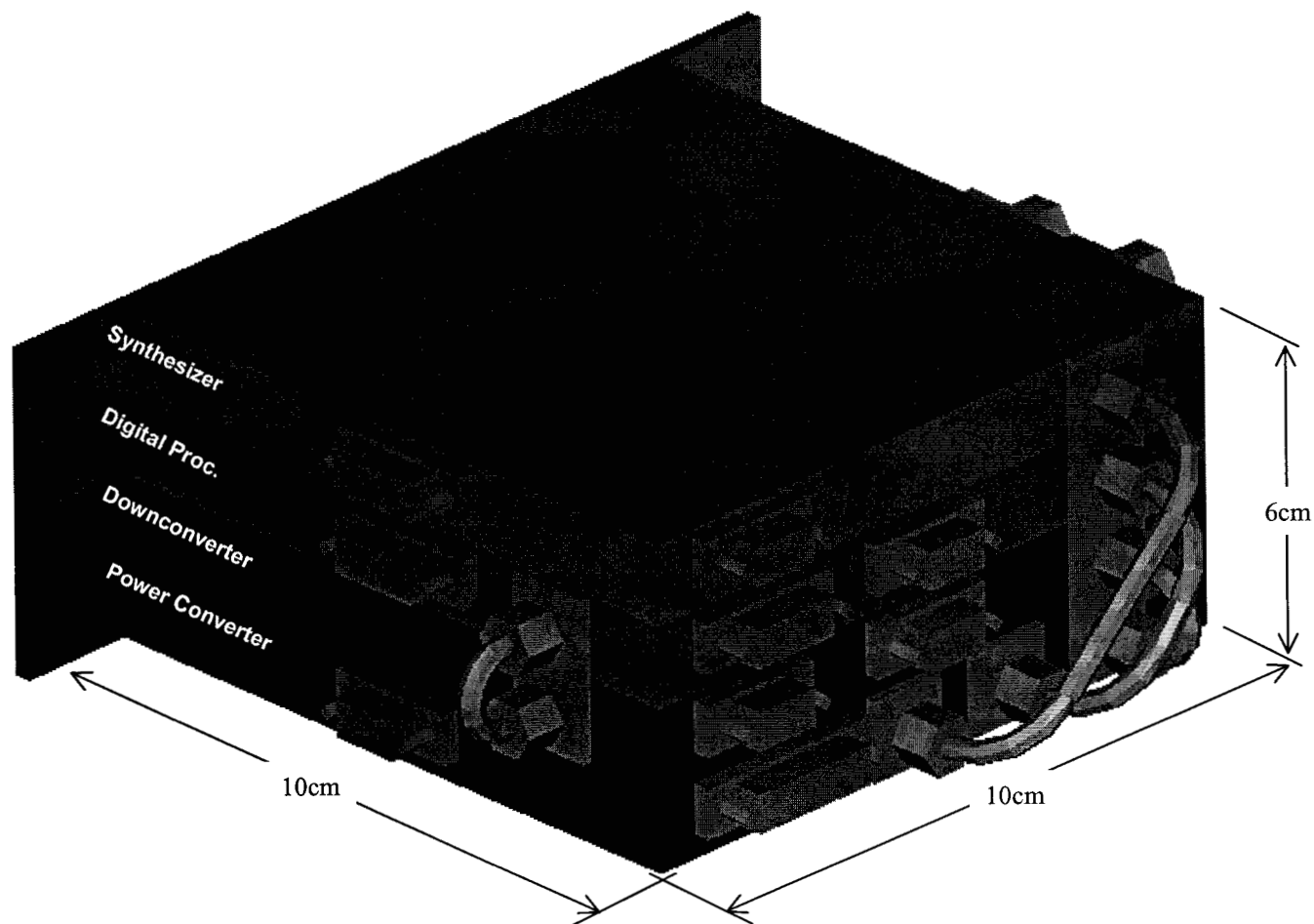
- POWER USAGE
  - UPLINK ONLY   8.1 W
  - UPLINK AND X-DOWN   11.7 W
  - UPLINK AND Ka-DOWN   13.5 W
- 4 SLICES
  - SYNTHESIZERS, DIGITAL, DOWNCONVERTER, AND POWER
  - ALLOWS ULTRA-STABLE OSCILLATOR (USO) ADDITION
- SIZE IS 10 cm X 10 cm X 6 cm
  - MCM CONSTRUCTION
  - ACTIVE DEVICE COUNT 70
  - RADIATION HARDNESS OF 100krad

ASSEMBLED STM

Synthesizer

Digital Proc.

Downconverter

Power Converter

6cm

10cm

10cm

CONCLUSIONS

- DELIVERY SCHEDULE SUPPORTS MISSIONS LAUNCHING IN LATE 2003
- SUPPORTS DECEASED MISSION TRACKING COSTS:
  - Ka-BAND DOWNLINK
    - HIGHER DATA RATES, IN LESS TIME
  - TURBO CODING
    - 0.8 dB CODING GAIN IMPROVEMENT OVER CONCATENATED (15, 1/6) CONVOLUTIONAL/REED-SOLOMON
  - REGENERATIVE RANGING
    - UP TO 30 dB INCREASE IN RECEIVED RANGING POWER-TO-NOISE SPECTRAL DENSITY
- CODEBLOCK-LEVEL COMMAND INTERFACE
- FRAME-LEVEL TELEMETRY INTERFACE